BIOLOGICAL MEDIATION OF MATERIAL FLUXES ACROSS THE SEDIMENT-WATER INTERFACE IN ESTUARIES AND COASTAL SYSTEMS

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LONG-TERM GOALS

The strong association of contaminants with fine-grained or organic-rich sediments is well established. Contaminants focused at the sediment-water interface may be resuspended, transported, transformed or buried, depending on the phasing and interactions among biological, physical and chemical processes. Our long term goal is to develop a better understanding of how materials are exchanged across the sediment-water interface and how these process influence the transport and fate of contaminants in coastal ecosystems. A knowledge of these processes is essential for ecological risk assessments for sediment-associated contaminants and for designing effective remediation strategies for contaminated coastal harbors.

SCIENTIFIC OBJECTIVES

The major objectives of our field and laboratory based studies are to characterize the rates, magnitudes, frequencies and mechanisms of particle and fluid exchanges across the sediment-water interface in selected environments. We are characterizing patterns and processes over a range of spatial (cm to km) and temporal scales (minutes to 10s of years) relevant to the estuarine - coastal ocean gradient. A strongly coupled goal is to determine how and when these processes control the transport and fate of contaminants. In order to accomplish our objectives we are comparing 'endmember' sites characterized by different levels of bioturbation, and which vary in the relative importance of hydrodynamic forcings (e.g. waves, tidal currents), sediment inputs and contaminant loadings.

APPROACH

We employ a multidisciplinary approach to characterize processes and process interactions in the benthic boundary layer, including the upper seabed. Thus far our work has been concentrated in distinct, representative coastal environments. One site (CS - lower bay) is characterized by high levels of bioturbation, moderate tidal currents, moderate wave activity and minimal inputs of new sediment. A second site (YR - York River) is characterized by low levels of bioturbation, strong tidal currents, low wave activity and erosion/deposition events. Additional sites are located within selected urban estuaries where contaminant loadings are high (Elizabeth River, VA and Hudson River, NY). In field studies we (Friedrichs, Wright, Schaffner) use instrumented tripods with various sensors to characterize the flow regime (ADVs, ADCPs, pressure sensor) and particle characteristics (OBS, ABS, LISST). Natural and anthropogenic tracers and bulk measures are used to estimate parti! cle characteristics, sediment accumulation, resuspension, mixing, burial and fluid exchange (Kuehl, Schaffner, Dickhut). Photography, side-scan sonar and sub-bottom acoustics, sediment core x-radiography and microstructure analyses are used to document biological and physical bed reworking, structures and texture (Kuehl, Schaffner). Biotic communities are characterized via enumeration/identification of microbes-macrofauna-fish (Schaffner, Ducklow).

Effects of benthic communities on organic contaminant transport and fate are evaluated in laboratory microcosms (Schaffner, Dickhut). Our experiments examine mechanisms and rates of bioturbation and

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resuspension for selected organic contaminants (PAH, PCB) and contaminant flux across the sediment-water interface as a function of contaminant physical chemistry (e.g. structure, octanol-water partitioning coefficient, molecular diffusivities) and benthic community composition, including the presence of bottom-feeding fish.

WORK COMPLETED

Our work completed in 1997 was largely motivated by the investigations we completed during the first phase of our award. For example, Dellapenna et al. (in press) showed that physical processes at selected sites in the York River result in sediment mixing depths of 50 cm or more over the time scales revealed by ^{210}Pb and ^{137}Cs dating techniques (e.g. 40 years or less). The near-surface stratigraphic record at these sites is characterized by numerous hiatal surfaces characteristic of erosion events. Calculated particle residence times in the surface mixed layers are on the order of 100s of years. Physical sediment mixing of this magnitude was somewhat unanticipated given that the study sites are within the middle reaches of a muddy, microtidal estuary. Some of our preliminary sampling within the York River estuary also revealed high spatial and temporal variability in sedimentary regimes. To better understand variations in physical energy regimes,! sediment convergence processes, strata formation and benthic communities in fine-grained coastal environments, we began intensive field and modeling studies during the fall of 1996. During two major cruises we sampled over 100 sites for sediment grain size, water content, particulate organic carbon and nitrogen, chlorophyll a, and benthic fauna. A subset of the sites were sampled in greater detail for sediment geochronology studies. Subsequent cruises throughout the year have been used to address issues of temporal variability in the same parameters at a representative subset of the sites. Monthly sampling of the York River water column is focused on bacterial dynamics and associations with organic aggregates and suspended particles in the water column. Analyses of many samples collected during 1996-97 are still in progress.

A newly instrumented tripod for shallow water benthic biology and boundary layer studies (BIOPOD) christened during the summer of 1997 is being used for process studies. This tripod supports two ADVs, up to four underwater video cameras and additional sensors such as an ADCP and an ABS. Five short-term deployments of the tripod and LISST have been completed to provide resolution of temporal (spring vs. neap tide) and spatial (shoal vs. channel) variations in hydrodynamics, bed response, suspended sediment characteristics and benthic biology within the York River estuary. To compliment the field work, modeling studies have been used to: 1) provide a better understanding of the relationships between migrating mud layers, tidal energy and the formation of the estuarine turbidity maximum (Friedrichs et al. in press) and 2) examine along and across estuary gradients in physical energy regimes as they influence sedimentary regimes and benthic biology (Schaffner et al. 199! 7).

We are continuing our investigations of biological/physical interactions as they mediate particle and contaminant exchange across the sediment-water interface at actively bioturbated coastal sites. In previous studies we found that biological processes interact with physical processes to control sediment resuspension and particle mixing, that bioturbation interacts with physico-chemistry to control the fate of organic contaminants and that bioturbation processes in a temperate estuarine environment are highly seasonal (Wright et al. 1997, Schaffner et al. 1997, Dellapenna et al. in press) . In September 1997 we completed a cruise to the CS site in lower Chesapeake Bay, aimed at looking at the distribution of the particle tracer Be-7 as influenced by benthic-pelagic coupling processes, particularly the activities of suspension feeders and head-down deposit feeders. We collected water column samples as well as deposit and suspension feeders and dissected worm burrows, ! feeding voids and surface fecal pellet deposits to look at the uptake and distribution of
Be-7. Unfortunately, our summer was dry and the inventory of Be-7 in the water column was very low. We hope to repeat this experiment in late Spring or early Summer 1998.

Time-series measurements of suspended-sediment Be-7, Th-234 and Pb-210 activities at various depths above the seabed provide information on water-column mixing and sediment exchange between the water column and seabed at the CS site. Samples collected during the fall of 1996 at 0.25m, 0.45m and 2m above the bottom over a 24-hour cycle showed little systematic variation of Be-7 during the initial 18 hours, suggesting thorough particle mixing in the boundary layer over the characteristic time-scale of radioactive decay (half-live 53 days). In contrast, shorter lived Th-234 (half life 24 days) showed suspended sediment activities decreasing with depth through the time series, indicating the dilution of Th-234 activities in the lower portion of the boundary with "older" sediment through sediment resuspension. Pb-210, with its much longer characteristic time scale (half life 22.3 years) did not vary appreciably with depth or time. During the latter third of the time seri! es, Be-7 activities for the 2 m samples spiked, increasing from about 20 dpm/g to over 100 dpm/g. Water column CTD measurements conducted during the same time show a significant and rapid destratification event. We suggest that this resulted in the rapid downward transport of surface suspended sediments, carrying high Be-7 activity. For the same time series, relationships between particle size distributions measured using LISST and biogeochemical properties such as total organic content, chl a and Be-7 activities are being examined using inverse modeling approaches. Results to date indicate that most particles are aggregates and that finer aggregates contain relatively more organic matter, chlorophyll a and have higher Be-7 activities than larger aggregates.

RESULTS

The most consistent and significant findings of our studies to date concern the spatially and temporally dynamic nature of physical and biological processes and their interactions in the benthic boundary layer of coastal environments. For example, we have now shown that substantial mixing of the sediment column results at some sites in coastal environments that are characterized by fine-grained sediments but are also physically energetic. The physical energy regimes at these sites are influenced to varying degrees by tides, wind-driven currents, waves, estuarine gravitational circulation and interactions among these processes. This contrasts with many shelf and deep sea environments where the presence of fine-grained sediment deposits is correlated with reductions in the physical energy regime, but reminds us of larger river systems such as the Amazon where high energy and high rates of sediment input lead to dynamic, energetic fine-grained environments. In other ar! eas of the estuary bioturbation processes are among the highest measured for temperate coastal ecosystems. Despite different mixing controls (i.e. biological (diffusive) versus physical (advective)), deep mixing and low accumulation result in long particle residence times ($\approx 10^2$ years) at our study sites and an increased potential for contaminant recycling prior to degradation or burial.

IMPACT/APPLICATIONS

The relative importance of various biological, physical and chemical processes governing the flux of materials, including contaminants, at the sediment-water interface are being elucidated for distinct end-member benthic environments characteristic of temperate coastal and estuarine ecosystems. In particular, our work is some of the first to focus on sediment and contaminant transport and mixing processes in biologially productive, physically energetic, fine-grained coastal environments. A knowledge of how contaminants are transported and transformed within the benthic boundary layer of coastal environements is fundamentally important for ecological risk assessments and effective remediation of anthropogenic contaminants.

TRANSITIONS

We are using regular presentations at scientific meetings on national and regional levels to interface with both the scientific and management communities regarding our significant findings.

RELATED PROJECTS

Our work is being conducted in close association with the project entitled "Particulate Organic Matter - Contaminant Associations at the Water - Sediment Interface: Biological and Physical Controls", Elizabeth Canuel (PI), Rebecca Dickhut (Co-PI).

REFERENCES

Dellapenna, T.M., Kuehl, S. A., and L. C. Schaffner, in press. Seabed mixing and particle residence times in biologically and physically dominated estuarine systems: a comparison of lower Chesapeake Bay and the York River subestuary. Estuarine, Coastal and Shelf Science.

Friedrichs, C.T., B.A. Armbrust, and H.E. de Swart. in press. Hydrodynamics and sediment dynamics of shallow, funnel-shaped tidal estuaries. J. Dronkers (ed.), Physics of Estuaries and Coastal Seas, Balkema Press, Rotterdam, The Netherlands.

Schaffner, L. C., R. M. Dickhut, S. Mitra, P. W. Lay and C. Brouwer-Riel. 1997. Effects of physical chemistry and bioturbation by estuarine macrofauna on the transport of hydrophobic organic contaminants in the benthos. Environ. Sci. Technol.

Schaffner, L. C., C. T. Friedrichs, K. Dorgan, E. Hinchey, M. Smith, T. Dellapenna, S. Kuehl and M. Thompson. Physical energy and sediment regimes along the York River - Lower Chesapeake Bay estuarine gradient. 14th Biennial Estuarine Research Federation Conference, Providence, PI, October 12-16 1997.

Wright, L.D., L.C. Schaffner, and J. P-Y. Maa. 1997. Biological mediation of bottom boundary layer processes and sediment suspension in the lower Chesapeake Bay. Marine Geology.

Effects of Physical Energy Regimes and Other Processes on PAH Distributions in Sediment Pore Waters of Coastal Harbors and Estuaries

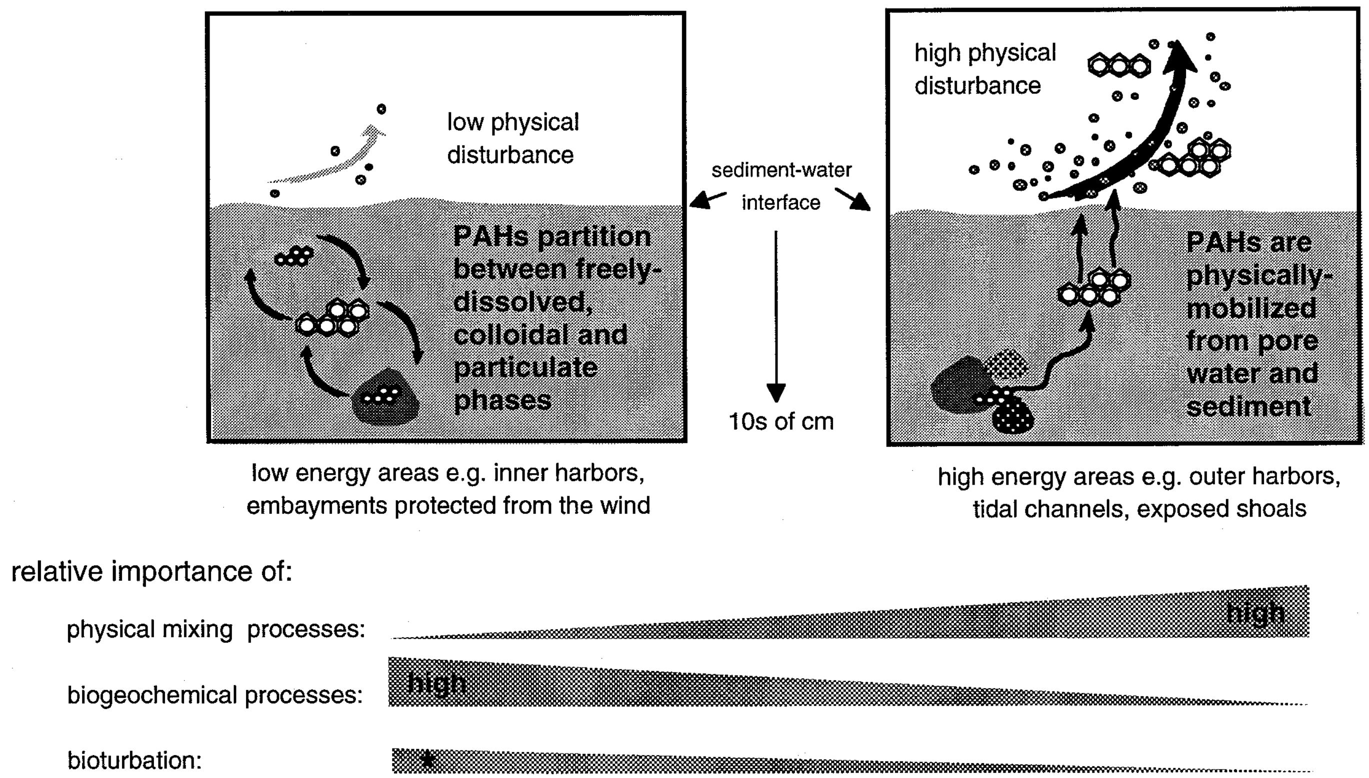

Figure 1. Our studies indicate that physical energy associated with tides, wind waves and currents is sufficient to cause substantial disturbance of fine-grained sediment deposits in some coastal areas (Dellapenna et al. in press, Mitra 1997, Schaffner et al. 1997). Physical mixing of the seabed has major implications for contaminant behavior and bioavailability. At a physically-mixed site in the East River, NY, Mitra (1997) found that PAHs were depleted in sediment pore water, despite high sediment contamination. He hypothesized that pore water PAHs at the site are continuously mobilized from the bed rather than equilibrated with surrounding sediment particles. At lower energy sites, which may be typical of most inner harbor regions, PAH distributions are greatly influenced by particle and pore water biogeochemistry (Mitra 1997). Bioturbation effects on pore water PAH concentrations are expected to be important only when physical mixing is low (Dellapenna et al. in press) and when sediment toxicity does not limit macrofauna communities (* indicates region where macrofaunal effects could vary widely due to sediment toxicity).